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WITH 175 MHZ CENTER FREQUENCY

by

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THE DESIGN OF A COMPOSITE ACOUSTO-OPTIC CELL  
WITH 175 MHz CENTER FREQUENCY

Cheng Naiping Li Shujian Shao Dingrong

ABSTRACT Introduction is made of a design for composite acousto-optic cells with center frequencies of 175 MHz and using PM (PbMoO<sub>2</sub>) as medium. Transducer bandwidths are calculated when In is used as adhesive layer. In conjunction with that, coating thicknesses are precisely determined. The cell bandwidth in question is 120 MHz. Time bandwidth products reach 1207.5. The requirements of acousto-optic processing are satisfied in a preliminary way.

KEY WORDS Acousto-optic devices Design Information processing Bragg cell

CLASSIFICATION CODE TN65

## 1 INTRODUCTION

Following along with the rapid development of acousto-optic signal processing technology, there is a requirement for acousto-optic devices to possess time bandwidth products ( $\tau B$  products) which are as large as possible. Transition times  $\tau$  depend on the dimensions of acousto-optic media and optical system aperture diameter. They cannot be too large. With regard to normal Bragg cells,  $\tau$  is generally selected as around  $10\mu\text{s}$ . What has the most relative potential is increasing device bandwidth  $B$  (or  $\Delta f$ ). Due to the fact that when acousto-optic devices operate, they generally do not exceed octave bandwidths[1], that is, relative wavelength  $\Delta f/f_c \leq 0.667$  ( $f_c$  in this is center frequency), as a result, the key to increasing device bandwidth  $\Delta f$  is increasing the device center frequency  $f_c$  to act as the first step in developing ultra high frequency wave band acousto-optic devices. As far as our developing acousto-optic devices with center frequencies of 175 MHz and bandwidths reaching 120 MHz is concerned, the time bandwidth product can reach 1000. This is able to satisfy requirements associated with acousto-optic signal processing in a preliminary way.

At the present time, correlator/coil integral device systems developed inside and outside China basically all opt for the use of dual device systems. The obvious drawback of the systems in question are variety, large light losses, and bad stability characteristics. In order to make systems capable of conversion to practical use as rapidly as possible, a design is put forward of two transducers glued to the two ends of a crystal, designing composite acousto-optic devices--not only greatly simplifying the systems but also greatly improving system performance.

## 2 GENERAL CONSIDERATIONS

Due to the fact that supersonic wave attenuation associated with media and  $f^2$  form a direct proportion, when developing ultra high frequency acousto-optic devices, the primary consideration is supersonic attenuation. Data associated with supersonic attenuation coefficients of a number of relevant media as well as the speed of sound  $V$ , acoustic impedance  $Z$ , and relative acoustic impedance  $Z_0=Z/Z_{op}$  ( $Z_{op}$  is the acoustic impedance associated with LN transducer plates) are set out in Table 1[1].

PM (PbMoO<sub>3</sub>) is one of the most commonly used acousto-optic media in the visible light and near infrared range. It possesses a very large acousto-optic optimum value.  $\alpha_0$  associated with 36°Y sheared niobium lithate is very small. Using it as a high frequency band piezoelectric layer is no problem at all. The typical thickness of adhesive layers and electrode layers is  $1\mu\text{m}$ . Indium is selected as the linking layer material. The  $\alpha_0$  associated with silver and gold are both very small. There is no problem using them as electrode layers. Considering that back electrodes are constantly in contact with the air, it is very easy

for silver to blacken when it is used. It is possible to change to the use of gold. When calculating the thicknesses of various coating layers, option should be made--as much as possible--for the use of thin film material data (Table 1). In conjunction with this, assume the internal resistance of unitary sources,  $r$ (illegible) = 1.

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Table 1 Acoustic Characteristics Associated with Several Types of Important Acousto-Optic Materials

① 介质(声波方向)	$\alpha_0$ (dB/cm · GHz <sup>2</sup> )	$V$ ( $\mu\text{m}/\mu\text{s}$ )	$Z(10^6\text{kg/m}^2 \cdot \text{s})$	$Z_e = Z/Z_{\infty}$
② 钨酸铅 $\text{PM}([001])$	15	3 632	25.2	0.75
③ 钨酸锂 $\text{LN}(36^\circ\text{Y})$	0.15	7 300	33.9	1.00
$\text{In}([101])$	80 000	2 250	16.4	0.48
$\text{Ag}([111])$	250	3 960	41.5	1.22
$\text{Au}([111])$	200	3 400	65.5	1.93

Key: (1) Medium (Acoustic Wave Direction) (2)  $\text{PbMoO}_2$   
(3) Niobium Lithate

### 3 TRANSDUCER BANDWIDTH CALCULATIONS AND PRECISE DETERMINATIONS OF COATING THICKNESSES

The general structure of acousto-optical devices as well as related parameters are as shown in Fig.1.  $\rho$ ,  $V$ , and  $l$ , respectively, stand for the density, acoustic speed, and thickness of various layers. With regard to piezoelectric layers, there is also a need to add electromechanical coupling coefficient  $k$  and transducer thin plate tweezers shape electrical capacitance  $C_0$ .

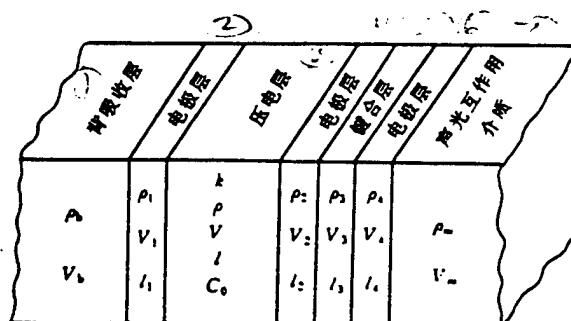


Fig.1 General Structure of Acousto-Optical Devices and Related Parameters

Key: (1) Back Absorption Layer (2) Electrode Layer (3) Piezoelectric Layer (4) Electrode Layer (5) Linkage Layer (6) Electrode Layer (7) Acousto-Optically Interacting Media

The importance of electrode layers 11 and 12 is obvious. The role of linkage layer 13 is to take mechanical vibrations associated with piezoelectric layers and couple them into interacting media forming supersonic waves. The rationale for electrode layer 4 must be because of technical reasons. It makes interacting media surfaces metalized in order to facilitate linkage. As far as the existence of back absorption bodies is concerned--although it is possible to enlarge transducer bandwidth--at the same time, however, it makes useful (that is, entering into interacting media) supersonic energies become smaller. Under general conditions, back absorption bodies are not used at all.

Any acousto-optic device is capable in all cases of using the medium composition set out below in order to be characterized:

$$Z_{ob} - (Z_{o1}, t_1) - P(k) - (Z_{o2}, t_2) - (Z_{o3}, t_3) - (Z_{o4}, t_4) - Z_{om}$$

$t_n$  is the relative thickness of various coating layers ( $n=1, 2, 3, 4$ ).

$Z_{ob}$ ,  $Z_{om}$ ,  $Z_{on}$  are the realtive impedances associated with various layers ( $n=1, 2, 3, 4$ ).

During the selection of calculation attempt values associated with  $t_2$ ,  $t_3$ ,  $t_4$ , considerations are made of the several areas below.

1) As far as technical considerations are concerned, one first of all wishes  $t_3$  to be relatively large in order to facilitate linkage. However, with regard to  $t_2$  and  $t_4$ , they are chosen very small. Moreover, calculation results associated with changing  $t_3$  values clearly show that, at this time, the transducer 3dB bandwidth reductions which follow along with increases in  $t_3$  are relatively fast. The reason is that the difference between  $Z_{o3} = 0.48$  and 1 is relatively large. Acoustic match losses associated with this situation are relatively severe.

2) Making considerations in terms of technology, selecting  $t_4=t_2$  is the most advantageous. At this time, silver plating operations on LN and PM can be completed at one time.

3) Due to the fact that indium's  $V/2=1125$  is nearly only half of silver's ( $V/2=1980$ ), as a result, if one selects  $t_3=t_2$ , then, the actual thickness of indium layers is too thin--not advantageous to linkage.

For this reason, when selecting calculation attempt values associated with  $t_2$ ,  $t_3$ , and  $t_4$ , the limits set out below will be made:

$$t_3=2t_2 \quad t_4=t_2$$

In accordance with data in Table 1, calculations are done of media composition

$$(1.93, t_1) - P(0.49) - (0.48, 2t_2) - (1.22, t_2) - 0.75$$

TL-F curves (in these,  $f_0$  is piezoelectric transducer plate antiresonance frequency). In conjunction with this, in accordance with transducer requirements, precise determinations are made of relative coating thicknesses  $t_1$  and  $t_2$ .

Table 2 and Table 3 set out the primary characteristic data associated with TL-F curves. Among these,  $F_m$  is peak value frequency, that is, when transducer losses TL reach extremely small values  $TL_{min}$ , relative frequencies  $F_L$  and  $F_H$  are, respectively, the low end and high end frequencies associated with  $TL=TL_{min}+3$  dB locations (that is, 3dB bandwidths).  $F_c=(F_L+F_H)/2$  gives band pass center frequencies. Moreover,  $\Delta F=F_H-F_L$  gives 3 dB relative band width. Due to the fact that  $f_0/f_c=F_c$ , from center frequency  $f_c$ , it is possible to precisely determine the antiresonance frequencies  $f_0$  for which piezoelectric transducer plates should possess.  $\Delta f/f_c=\Delta F/F_c$  gives relative bandwidths with practical uses. They should correspond to 3dB Bragg bandwidths of devices. From Table 2 data it is possible to see that, when  $t_2 \leq 0.08$ , curve forms are very close to when  $t_2 = 0.00$  (in particular, within 3dB bandwidth ranges). Bandwidth  $\Delta F$  is basically invariable. However, after  $t_2 \geq 0.08$ , curve forms are then clearly distorted.  $\Delta F$  very rapidly gets small. As a result,  $t_2 = 0.08$ . From Table 3 data, it is possible to see that, when back electrode layer relative thickness  $t_1$  increases, although changes in the magnitudes of  $\Delta F$  and curve shapes are very small, the entire curve, however, will rapidly shift toward the low end, thereby making the values of  $f_0/f_c$  increase. The larger  $f_0/f_c$  values become, the higher antiresonance frequency  $f_0$  associated with piezoelectric transducer plates must become in order to realize the same type of center frequency  $f_c$ . This requires taking transducer plates and grinding them even thinner. In view of the limitations associated with transducer thinning techniques, it is not desired to have  $f_0/f_c$  values too large. From Table 3 data, selecting  $t_1 = 0.04$  is comparatively appropriate. At this time, transducer relative bandwidths are already larger than the octave bandwidth 0.667 required by normal Bragg devices. As a result, it is possible to satisfy requirements. It should be pointed out that, as far as Table 3 is concerned--although it is only results fixed at 0.08-- $t_2$  calculation results, however, are almost completely the same at different values, that is, a selection of  $t_1 = 0.04$  possesses general occurrence.

Table 2 Primary TL-F Curve Characteristic Data Associated with  $P(0.49)-(0.48,2t_2)-0.75$

$t_2$	$F_m$	$F_L$	$F_H$	$F_c$	$\Delta F$	$f_0/f_c$	$\Delta f/f_c$
0.00	0.89	0.53	1.21	0.87	0.68	1.15	0.78
0.08	0.92	0.535	1.205	0.87	0.67	1.15	0.77
0.12	0.94	0.59	1.12	0.85	0.53	1.18	0.625
0.16	0.90	0.675	1.03	0.85	0.355	1.18	0.42

Table 3 Primary TL-F Curve Characteristic Data Associated with (1.93,t1)-P(0.49)-(0.48,2t2)-0.75

$t_1$	$F_m$	$F_L$	$F_H$	$F_c$	$\Delta F$	$f_0/f_c$	$\Delta f/f_c$
0.00	0.92	0.535	1.205	0.87	0.67	1.15	0.77
0.04	0.83	0.485	1.12	0.80	0.635	1.25	0.794
0.08	0.77	0.455	1.045	0.75	0.59	1.33	0.786

Synthesizing the analysis above, precise determinations of various layer thickness parameters are as follows:

(1.93,0.04)-P(0.49)-(1.22,0.08)-(0.48,0.16)-(1.22,0.08)-0.75  
With regard to the selections above, there are:  $f_0/f_c = 0.794$ .  
The devices associated with designs in this article operate at locations where center frequencies are  $f_c = 175\text{MHz}$ . It is then possible to obtain

$$f_0=1.25f_c=218.75(\text{MHz})$$

$$\Delta f_T=0.794f_c=138.95(\text{MHz}) \quad (\text{transducer bandwidth})$$

Various layer thicknesses:

$$l=V/2/f_0=3650/218.75=16.7(\mu\text{m})$$

$$l_1=V/2/f_0x t_1=1700/218.75x 0.04=0.31(\mu\text{m})$$

$$l_2=l_4=1980/218.75x 0.08=0.72(\mu\text{m})$$

$$l_3=V_3/2/f_0x t_3=1125/218.75x 0.16=0.82(\mu\text{m})$$

In these,  $l$  is piezoelectric layer thickness.  $l_1, l_2, l_4$  are electrode layer thicknesses.  $l_3$  is adhesive layer thickness. In technical terms, these kind of coating thicknesses are relatively easy to realize.

Due to the fact that, when designing various coatings, the assumed unitized internal resistance  $r_s=1$ --in theoretical terms--during operations, wide band acousto-optical devices are capable of not adding matching networks. Moreover, in terms of design, electrode area  $A$  is made so that  $1/(\omega_0 C_0)=R_s$ . Generally, electric source internal resistance  $R_s=50\Omega$ . As a result,  $1/(\omega_0 C_0)=50\Omega$ . From flat plate electrical capacitance formulae, one obtains a unit area capacitance of:

$$C_{\text{unit}}(\text{pF/mm}^2)=8.85\epsilon_r/(l(\mu\text{m}))$$

In this,  $l$  is transducer plate thickness calculated above corresponding to  $f_0$ .  $\epsilon_r$  is the relative dielectric constant associated with LN. Because of this, unit area capacitance is:

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$$1/(\omega_0 C_{\text{unit}})=1/(2\pi f_0 C_{\text{unit}})$$

Then,

$$A = 1 / (\rho_0 C) / 50$$

With regard to device designs in this article, when  $\rho$  is associated with  $36^\circ$  Y shear  $LN = 38.6$ , one solves to get  $l = 16.7 \mu\text{m}$ . Upper electrode area  $A = 0.712 \text{mm}^2$ .

#### 4 ACTUAL DESIGNS AND BRAGG BANDWIDTHS

Opting for the use of planar first order supersonic tracking structures ( $N_e = 4$ ), in order to increase Bragg bandwidth  $\Delta f_B$ , when  $f_c = 175 \text{MHz}$  and  $\lambda_0 = 0.6328 \mu\text{m}$ , PM internal medium optical wavelength  $\lambda = 0.2723 \mu\text{m}$ . The speed of sound  $V = 3632 \text{m/s}$ . As a result, characteristic wavelengths associated with center frequency locations are:

$$L_0 = \lambda^2 / (V/f_c) 2 / \lambda = 1.582 (\text{mm})$$

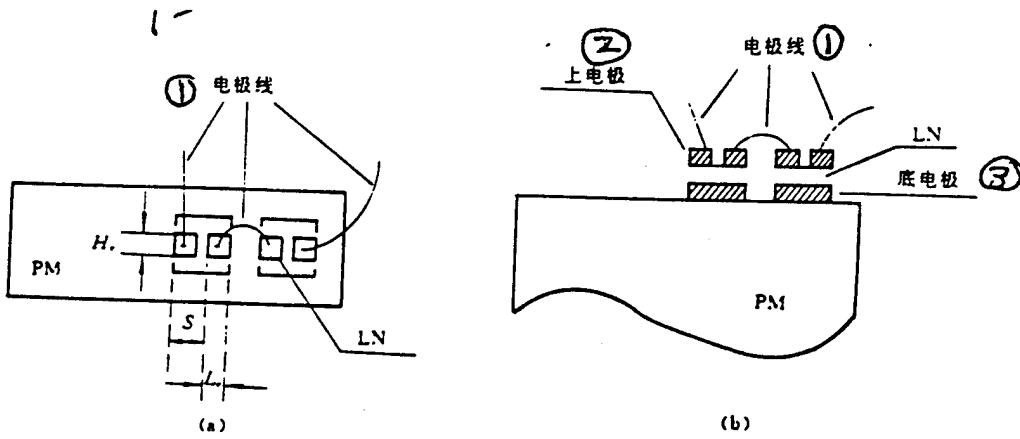


Fig.2 Planar Structure First Order Supersonic Tracking Structure ( $N_e = 4$ )

Key: (1) Electrode Line (2) Upper Electrode (3) Base Electrode

Then, from the optimum designs of Table 4:  
various transducer plate center distances

$$S = 1.167 \quad l = 1.85 (\text{mm})$$

various transducer plate lengths

$$L_e = 0.9S = 1.66 (\text{mm})$$

overall interaction length

$$L = 4S = 7.40 (\text{mm})$$

3dB Bragg bandwidth

$$\Delta f_B = 0.69 f_c = 120.75 (\text{MHz})$$

Because  $\rho = 1$  is selected, option is, therefore, made for the use of anitresonance drive methods. Various transducer plates act

as series electrical connections. Polarization directions are more or less the same as LN.

$N$	$F_1+F_2$	$1/F_1F_2$	调整角度 $\beta$	设计参数 $S$	$L$	$\Delta f$
4	2	1.167	$2\theta_c$	$1.167L_0^{(c)}$	$4.668L_0^{(c)}$	1.22
6	2	1.124	$2\theta_c$	$1.124L_0^{(c)}$	$6.774L_0^{(c)}$	1.02
8	2	1.097	$2\theta_c$	$1.097L_0^{(c)}$	$8.776L_0^{(c)}$	0.88
10	2	1.080	$2\theta_c$	$1.080L_0^{(c)}$	$10.80L_0^{(c)}$	0.80
12	2	1.068	$2\theta_c$	$1.068L_0^{(c)}$	$12.816L_0^{(c)}$	0.74

注:  $F_1+F_2=2$ ;  $r=0.9$ ;  $\rho=1$

Table 4 Planar Structure First Order Supersonic Tracking Optimum Designs

Key: (1) Adjustment Angle (2) Design Parameter (3) Note

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Because, when single plate structures are changed into series connected four plate structures, it is equivalent to four parallel connected plates changed into four series connections, as a result, transducer capacitance amounts are reduced 16 fold. In order to maintain  $1/(\omega_0 C_0)=50\Omega$ , it should make transducer overall area increase 16 fold. Each transducer plate area increases 4 fold. At this time, each base electrode area  $A_e=4A=0.172 \times 4=2.848 \text{ mm}^2$ . As a result, the width of each base electrode  $He=A_e/L_e=2.848/1.66=1.72 \text{ mm}$ .

The dimensions of this type of electrode are easily manufactured.

Supersonic transition time periods associated with designs in this article are:  $\tau=10\mu\text{s}$ , that is, PM optical window length is:  $D=V\tau=3.632 \times 10=36.32 \text{ mm}$ . Then, acousto-optic device time period bandwidths are:  $B\tau=120.75 \times 10=1207.5$ . Processing gain is  $G_p=10\log B\tau=31 \text{ dB}$ .

## 5 CONCLUDING REMARKS

Due to the fact that it is very difficult to obtain large pieces of crystal, as a result, dimensions of devices worked are somewhat smaller than the designs. Actual technological indices and design indices show certain differences in comparisons. In actuality, the optical window lengths are only 27mm. Supersonic transition time periods are  $7.4\mu\text{s}$ . Transducer back electrode dimensions are  $L_e \times He=2 \text{ mm} \times 2 \text{ mm}$ . The center distance between two adjacent transducer plates is  $S=3 \text{ mm}$ . In this way,  $r=L_e/S=2/3=0.667$ . Ideal requirements have not yet been reached. A certain influence is produced on sound wave interference, directly influencing Bragg bandwidths associated with devices. Actual measured device bandwidth (3dB) is 72 MHz. Time bandwidth products  $\tau\Delta f=532.8$ ; processing gain  $G_p=27.3 \text{ dB}$ . Due to the fact that the relationship between signal to noise ration SNR associated

with correlation outputs and signal to noise ration SNR1 associated with reception signals is  $\text{SNR} = \tau \Delta f \cdot \text{SNR1}$ , SNR which is associated with correlation output and obtained by calculations in accordance with actual parameters ( $\tau \Delta f = 532.8$ )--although it does not attain ideal values demanded by designs--still obtains, however, obvious improvements. This is what present SAW devices have no way to achieve.

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